

Anesthesiology
1999; 91:991-8
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Comparable Postoperative Pulmonary Atelectasis in Patients Given 30% or 80% Oxygen during and 2 Hours after Colon Resection

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Received from the Outcomes Research™ Group, Departments of Anesthesia and General Intensive Care, Internal Medicine-Pulmonology, and Radiology and Radiodiagnosics, University of Vienna, Vienna, Austria; Department of Anesthesiology, Washington University, St. Louis, Missouri; Department of Anesthesia and Perioperative Care, University of California-San Francisco, San Francisco, California; and the Ludwig Boltzmann Institute for Clinical Anesthesia and Intensive Care, Vienna, Austria. Submitted for publication September 14, 1998. Accepted for publication May 10, 1999. Supported by grant GM58273 from the National Institutes of Health, Bethesda, Maryland; the Joseph Drown Foundation, Los Angeles, California; and the Fonds zur Förderung der wissenschaftlichen Forschung, the Bürgermeister Fond der Stadt Wien, and the Austrian National Bank Fund, Vienna, Austria. Major corporate funding for the Outcomes Research™ Laboratory is provided by Augustine Medical, Inc., Eden Prairie, Minnesota. The authors do not consult for, accept honoraria from, or own stock or stock options in any anesthesia-related company.

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Background: High concentrations of inspired oxygen are associated with pulmonary atelectasis but also provide recognized advantages. Consequently, the appropriate inspired oxygen concentration for general surgical use remains controversial. The authors tested the hypothesis that atelectasis and pulmonary dysfunction on the first postoperative day are comparable in patients given 30% or 80% perioperative oxygen.

Methods: Thirty patients aged 18–65 yr were anesthetized with isoflurane and randomly assigned to 30% or 80% oxygen during and for 2 h after colon resection. Chest radiographs and pulmonary function tests (forced vital capacity and forced expiratory volume) were obtained preoperatively and on the first postoperative day. Arterial blood gas measurements were obtained intraoperatively, after 2 h of recovery, and on the first postoperative day. Computed tomography scans of the chest were also obtained on the first postoperative day.

Results: Postoperative pulmonary mechanical function was significantly reduced compared with preoperative values, but there was no difference between the groups at either time. Arterial gas partial pressures and the alveolar-arterial oxygen difference were also comparable in the two groups. All preoperative chest radiographs were normal. Postoperative radiographs showed atelectasis in 36% of the patients in the 30%-oxygen group and in 44% of those in the 80%-oxygen group. Relatively small amounts of pulmonary atelectasis (expressed as a percentage of total lung volume) were observed on the computed tomography scans, and the percentages (mean ± SD) did not differ significantly in the patients given 30% oxygen (2.5% ± 3.2%) or 80% oxygen (3.0% ± 1.8%). These data provided a 99% chance of detecting a 2% difference in atelectasis volume at an α level of 0.05.

Conclusions: Lung volumes, the incidence and severity of atelectasis, and alveolar gas exchange were comparable in patients given 30% and 80% perioperative oxygen. The authors conclude that administration of 80% oxygen in the perioperative period does not worsen lung function. Therefore, patients who may benefit from generous oxygen partial pressures should not be denied supplemental perioperative oxygen for fear of causing atelectasis. (Key words: Anesthesia; pulmonary function; pulmonary shunt; radiology; surgery.)

THE major complication associated with brief periods of oxygen administration is pulmonary atelectasis. Concern about atelectasis is appropriate because it occurs in up

to 85% of patients undergoing lower abdominal surgery and is thought to be an important cause of morbidity.¹⁻³ Two mechanisms contribute to perioperative atelectasis: compression and absorption. Compression results from cephalad displacement of diaphragm, decreased compliance, and reduced functional residual capacity.⁴⁻⁶ To some extent, these factors are present with any anesthetic technique. In contrast, absorption is defined by uptake of oxygen from isolated alveoli and results from administration of high oxygen partial pressures. Administration of 100% oxygen, even for a few minutes, causes significant postoperative atelectasis *via* this mechanism.^{2,7,8}

There is little doubt that high intraoperative oxygen concentrations produce atelectasis, at least in the immediate postoperative period.⁷⁻¹⁰ However, the extent to which this atelectasis impairs pulmonary function and gas exchange remains controversial.^{2,7-12} An additional complication associated with postoperative atelectasis is fever, which often prompts diagnostic evaluation or therapeutic intervention for potential infectious causes.

Intraoperative ventilation with high partial pressures of oxygen provides clinicians additional time to diagnose and treat inadvertent extubation, laryngospasm, and breathing-circuit disconnections.^{13,14} Oxygen *per se* also seems to be antiemetic,¹⁵ which is of substantial clinical importance because uncontrollable nausea and vomiting remains the leading cause of unanticipated hospital admission after planned ambulatory surgery.^{16,17}

Even patients with normal arterial oxygen saturation may experience regions of inadequate tissue perfusion as result of extreme positioning, surgical retractors, and operative disruption of blood vessels.¹⁸⁻²⁰ High arterial oxygen partial pressures help limit hypoxia in these marginally perfused tissues. High inspired oxygen concentrations may similarly help oxygenate penumbra tissues surrounding the core of a stroke.^{21,22}

Inspired oxygen concentration is a major determinant of tissue oxygen tension,²³ which, in turn, is highly correlated with oxidative killing of bacteria by neutrophils over the range of observed values.²⁴ Oxidative killing is the major defense against surgical wound infection.²⁵ Therefore, it is not surprising that tissue oxygen tension is highly correlated with the risk of surgical wound infection.²⁶ Collagen deposition and scar formation are also directly dependent on tissue oxygen tension.²⁷⁻²⁹ These data suggest that perioperative administration of high inspired oxygen concentrations may facilitate wound healing and improve resistance to surgical wound infections.

Available data thus indicate that high concentrations of inspired oxygen are associated with atelectasis but also provide recognized advantages. Consequently, the appropriate inspired oxygen concentration for general surgical use remains controversial. Concern about atelectasis prompts many clinicians to forego the benefits of generous inspired oxygen concentrations. Accordingly, we tested the hypothesis that atelectasis and pulmonary dysfunction on the first postoperative day are comparable in patients given 30% or 80% inspired oxygen during and for 2 h after colon resection.

Methods

The sample size for this study was based on atelectasis rates cited in previous studies.^{1,11} These data suggested that a power of 95% for detecting a 50% difference in atelectasis at an α level of 0.05 would be obtained with 13 patients in each group. With approval of the ethics committee of the University of Vienna, we studied 30 patients aged 18–65 yr who were scheduled to undergo elective colon resection. These patients were among the 500 who participated in the multicenter Study of Oxygen and Surgical Wound Infection. The procedure was identical for all patients. However, the special tests described in the Atelectasis section were performed only in the selected 30 patients.

Written informed consent was obtained from each patient. Patients with a history or current symptoms of acute or chronic pulmonary disease and patients in whom surgeons planned delayed primary closure techniques or wound healing by secondary intention were excluded, as were patients who had a history of fever or infection.

Protocol

Anesthesia was induced at an inspired oxygen fraction of 100% with sodium thiopental (3–5 mg/kg), vecuronium (0.1 mg/kg), and fentanyl (1–3 μ g/kg). Anesthesia subsequently was maintained with isoflurane (approximately 0.9%) in a carrier gas, described below in randomization groups. After tracheal intubation, the lungs were ventilated with a tidal volume of 10 ml/kg, with the rate adjusted to maintain end-tidal carbon dioxide partial pressure near 35 mmHg. Ventilation was volume-controlled with zero end-expiratory pressure.

After induction of anesthesia, patients were assigned to two groups using a reproducible set of computer-generated random numbers. The assignments were kept

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in sealed, sequentially numbered envelopes until used. For auditing purposes, both the assignment and the envelope number were recorded. The groups were: (1) 30% oxygen, balance nitrogen (*not* nitrous oxide); and (2) 80% oxygen, balance nitrogen.

At the end of surgery, residual neuromuscular block was antagonized with glycopyrrolate (0.4 mg) and neostigmine (2.5 mg). All patients were transported to the recovery unit after endotracheal extubation. During the first 2 h of recovery, the designated oxygen concentration was given *via* a nonbreathing mask system (AirCare mask and manifold; Apotheus Laboratories, Inc., Lubbock, TX). Subsequently, all patients breathed room air. Supplemental oxygen was given to patients in either group at any time, as necessary, to maintain oxygen saturation as measured by pulse oximeter > 92%. Postoperative analgesia was provided by patient-controlled intravenous doses of the opioid piritramid.

General Measurements

Appropriate morphometric characteristics of each treatment group were tabulated. Historical factors that might influence general health status of the participating patients were recorded. These parameters included smoking history, coexisting systemic diseases, alcohol abuse, and medication use.

An arterial blood gas measurement was obtained 1 h after induction of anesthesia and after 2 h of recovery at the randomly assigned fraction of inspired oxygen. The oxygen saturation from a pulse oximeter, end-tidal carbon dioxide partial pressure, end-tidal isoflurane concentration, and mean arterial blood pressure were measured at 15-min intervals during anesthesia. Saturation and blood pressure were recorded at 30-min intervals throughout recovery.

Posterior-anterior and lateral chest radiographs were obtained preoperatively per clinical routine. Additional posterior-anterior and lateral chest radiographs were obtained with patients in a semirecumbent position on the first postoperative day. All postoperative measurements were performed before patients were mobilized and before they first received chest physical therapy. The anesthesiologist and investigator assigned to perioperative management were aware of the group assignment. However, patients, nurses, surgeons, and other investigators were blinded to the group assignments. To maintain blinding, the perioperative blood gas results were not recorded on the postanesthesia care notes or elsewhere in patient records. The amount of postopera-

tive oxygen administered was similarly omitted from the patients' charts.

On the first postoperative day (approximately 24 h after surgery), a careful physical examination of the chest was performed to evaluate patients for respiratory complications, including pneumonia, pneumothorax, and clinical respiratory difficulties. Complications were scored with a three-point subjective scale: slight, moderate, or severe. Postoperative pain was evaluated with a 100-mm-long visual analog scale (0 mm = no pain and 100 mm = the worst imaginable pain).

Atelectasis

Spirometry was performed in with patients in the sitting position preoperatively and on the first postoperative day to determine lung volumes and flow-resistive properties of the lung. Spirometric measurements included the forced vital capacity and the forced expiratory volume in the first second. On the first postoperative day, arterial blood was sampled while the patients breathed room air. The radial artery was punctured with a 26-gauge needle attached to a capillary system (AVL Micro Sampler, Schaffhausen, Switzerland), and gas partial pressures were analyzed within 2 min of collection (ABL 510; Radiometer, Copenhagen, Denmark).

Chest radiographs were specifically evaluated for atelectasis with Joyce *et al.* modification of Wilcox severity scoring:³⁰ 0 = no atelectasis; 1 = plate atelectasis; 2 = segmental atelectasis; 3 = partial lobar atelectasis; 4 = complete lobar atelectasis; and 5 = complete lobar atelectasis in addition to any of the above.

Computed tomography (CT) scans of the chest were also obtained on the first postoperative day, approximately 24 h after surgery. CT scanning (Somatom Plus; Siemens, Erlangen, Germany) was performed with patients in the supine position with their arms positioned above the head. A frontal scout view covering the chest was obtained at the end of expiration. Subsequently, CT scans were obtained at the end of expiration: (1) 2 cm above the right costophrenic angle; (2) at the tracheal bifurcation; and (3) at two levels spaced equidistant between the first two scans. The scan time was 1 s at 165 mA and 137 kV. The slice thickness was 8 mm, and a matrix of 512 × 512 was used, resulting in a pixel (picture element) of approximately 1.5 × 1.5 mm. Lung density was defined in terms of Hounsfield units.¹² We considered the densities between -100 and +100 Hounsfield units as nonaerated (atelectasis) and the densities between -500 and -100 as poorly aerated areas.^{31,32}

All pulmonary function tests were performed by pulmonologists blinded to treatment group. Both sets of radiographs and the postoperative CT scans were evaluated by radiologists who were blinded to treatment group and to results of the pulmonary function tests.

Data Analysis

Each CT scan was separately examined for atelectasis. The dorsal border of atelectasis was manually highlighted. The ventral border between atelectasis and normal lung tissue was evaluated with Region of Interest software (Pulmo-software; Siemens). The exact amount of atelectasis was then calculated as sum of all pixels (picture elements) having a density between -100 and $+100$ Hounsfield units. Absolute lung area was calculated for each scan as atelectatic and aerated areas; these areas were averaged across the four scans. The extent of atelectasis was expressed in squared centimeters as a percentage of the total lung area.

The overall incidence of atelectasis in the two groups was compared with a chi-square analysis, whereas the percentage of atelectasis was evaluated with a Wilcoxon test. Pain scores were first averaged across the recovery period in each patient, and then among all patients. All clinical data, including physical examination scoring, arterial oxygen pressures, alveolar-arterial oxygen difference [(Aa)D_{O₂}], and pulse oximeter oxygen saturation were compared with unpaired two-tailed Student *t* tests. Time-dependent intragroup differences were evaluated by two-tailed paired Student *t* tests. Results are presented as means \pm SDs. A *P* value of 0.05 was considered statistically significant.

Results

Morphometric and demographic characteristics of the patients in each group were similar. There were four smokers among the patients given 30% oxygen and two among the patients given 80% oxygen (table 1). Preoperative pulmonary functions were comparable in the two groups, as were intraoperative hemodynamic responses and anesthetic management. The ratio of forced expiratory volume in the first second to forced vital capacity exceeded 70% in all but four patients.

During the recovery period, hemodynamic responses and the amount of piritramid given were similar in each group. Postoperative pain scores in the two groups did not differ significantly. Arterial oxygen partial pressure 1 h after induction of anesthesia and after 2 h of recovery

Table 1. Morphometric and Demographic Characteristics and Potential Confounding Variables

	F _I O ₂	
	30%	80%
No. of Patients	14	16
Age (yr)	41 \pm 10	49 \pm 14
Weight (kg)	61 \pm 16	71 \pm 11
Height (cm)	171 \pm 7	171 \pm 8
Gender (male/female)	7/7	9/7
ASA (1/2/3)	11/3/0	10/4/2
Smoking history (%)	29	13
Duration of operation (h)	2.8 \pm 1.0	3.3 \pm 1.0
Postoperative pain score (mm)*	30 \pm 20	20 \pm 24

Data are presented as means \pm SDs. There were no statistically significant differences between the two study groups.

ASA = American Society of Anesthesiologists physical status.

* Pain scores are presented as millimeters on a visual analog scale, with 0 mm being no pain and 100 mm being the worst imaginable pain.

differed significantly in the two groups, as might be expected from their differing inspired oxygen concentrations.

Three patients given 30% perioperative oxygen and five patients given 80% experienced slight respiratory difficulties or coughing on the first postoperative morning. Postoperative forced vital capacity and forced expiratory volume in the first second were significantly less than preoperative values, but there was no difference between the groups at either time. Arterial gas partial pressures and (Aa)D_{O₂} were also comparable in the two groups.

Atelectasis was not identified on any preoperative chest radiographs, whereas it was observed in 36% (5 of 14) of the patients in the 30%-oxygen group and 44% (7 of 16) of the patients in the 80%-oxygen group (*P* = not significant). Plate-like atelectasis was observed by chest radiograph in three patients in the 30%-oxygen group and seven in the 80%-oxygen group. Only two patients had segmental or partial lobar collapse, and both were in the 30%-oxygen group. The mean values of chest radiograph severity scores were similar in the two groups (*P* = 0.62).

Relatively small amounts of pulmonary atelectasis were observed on the CT scans, and the percentages did not differ significantly in the patients given 30% oxygen (2.5% \pm 3.2%) or 80% oxygen (3.0% \pm 1.8%). These data provided a 99% chance of detecting a 2% difference in atelectasis volume at an α level of 0.05 (table 2). Poorly aerated regions were also comparable between the groups (9.5% \pm 4.4% in the 30%-oxygen group *vs.* 10.3% \pm 4.2% in the 80%-oxygen group). There was a poor

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Table 2. Pulmonary Function and Atelectasis

	30%	80%	P
FVC (L)	3.8 ± 1.2	3.9 ± 1.1	0.82
Preoperative FEV ₁ (% predicted)	91 ± 15	94 ± 12	0.58
FEV ₁ /FVC (% predicted)	84 ± 10	81 ± 14	0.60
Intraoperative Pa _a O ₂ (mmHg)	138 ± 36	381 ± 67	< 0.001
Recovery Pa _a O ₂ (mmHg)	114 ± 37	234 ± 84	< 0.001
(Aa)DO ₂ (mmHg)	60 ± 33	212 ± 74	< 0.001
FVC (L)	2.0 ± 1.0	2.0 ± 0.6	0.98
FEV ₁ (%)	47 ± 15	53 ± 15	0.27
FEV ₁ /FVC	86 ± 12	86 ± 8	0.92
Pa _a O ₂ (mmHg)	78 ± 14	74 ± 8	0.36
Postoperative Pa _c O ₂ (mmHg)	36 ± 3	38 ± 4	0.22
Sa _a O ₂ (%)	95 ± 2	95 ± 2	0.45
(Aa)DO ₂	29 ± 13	30 ± 8	0.73
X-ray-determined atelectasis incidence (%)	36	44	0.94
CT-determined atelectasis incidence (%)	64	94	0.12
CT-determined atelectasis severity (%)	2.5 ± 3.2	3.0 ± 1.8	0.58

Preoperative values were obtained before induction of anesthesia. Recovery values were obtained 2 h after surgery, while patients were still given the designated inspired oxygen concentration. Postoperative values were obtained approximately 24 h after surgery. The arterial blood gas and computed tomographic (CT) analysis of atelectasis volume was also performed on the first postoperative day. Data are presented as means ± SDs. Postoperative FVC and FEV₁ were significantly less than preoperative values. These data provided a 55% chance of detecting a 1% difference in the atelectasis severity in the two groups and 99% chance of detecting a 2% difference at an α level of 0.05.

correlation between arterial partial pressure of oxygen (in millimeters mercury) on the first postoperative morning and the amount of atelectasis (%) detected by CT scanning: $-3.0(\text{atelectasis}) + 84$; $r^2 = 0.42$ (fig. 1). There was a poor correlation between (Aa)D_{O₂} (in millimeters mercury) on the first postoperative morning and the amount of atelectasis (%) detected by CT scanning: $(\text{Aa})\text{D}_{\text{O}_2} = 3.0(\text{atelectasis}) + 23$; $r^2 = 0.37$ (fig. 2). Examples of least and greatest amounts of atelectasis are

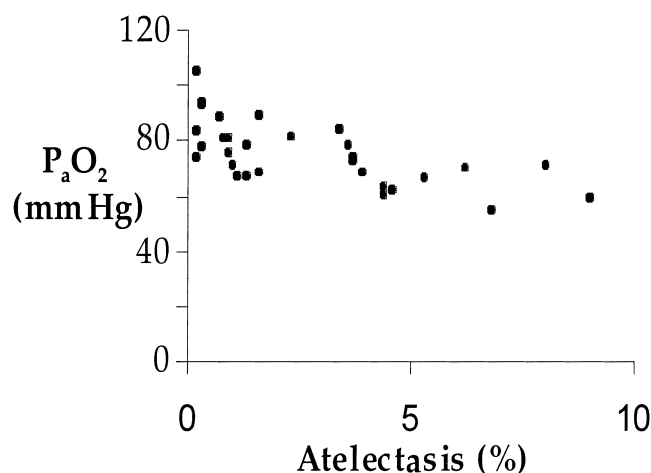


Fig. 1. There was a poor correlation between arterial partial pressure of oxygen (Pa_aO₂) on the first postoperative morning and the amount of atelectasis detected by computed tomography scanning: $\text{Pa}_{\text{a}}\text{O}_2 = -3.0(\text{atelectasis}) + 84$; $r^2 = 0.42$.

shown in figures 3 and 4, along with a typical amount of atelectasis.

When more than 0.5% atelectasis was considered significant, the incidence of atelectasis was 64% in the 30%-oxygen group and 94% in the 80%-oxygen group ($P =$ not significant). With a 1% atelectasis fraction considered potentially clinically important, the overall incidence of atelectasis was 70%, but, again, there was no statistically significant difference between the groups. Considering CT to be the standard, there were no false-positive but many false-negative radiographs.

The arterial partial pressure of oxygen on the first

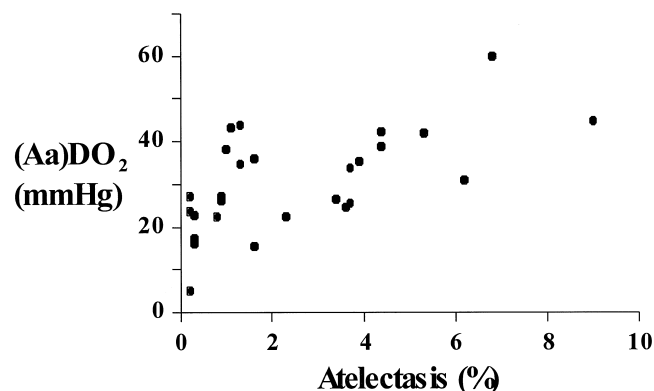


Fig. 2. There was a poor correlation between alveolar-arterial oxygen difference [(Aa)D_{O₂}] on the first postoperative morning and the amount of atelectasis detected by computed tomography scanning: $(\text{Aa})\text{D}_{\text{O}_2} = 3.0(\text{atelectasis}) + 23$; $r^2 = 0.37$.

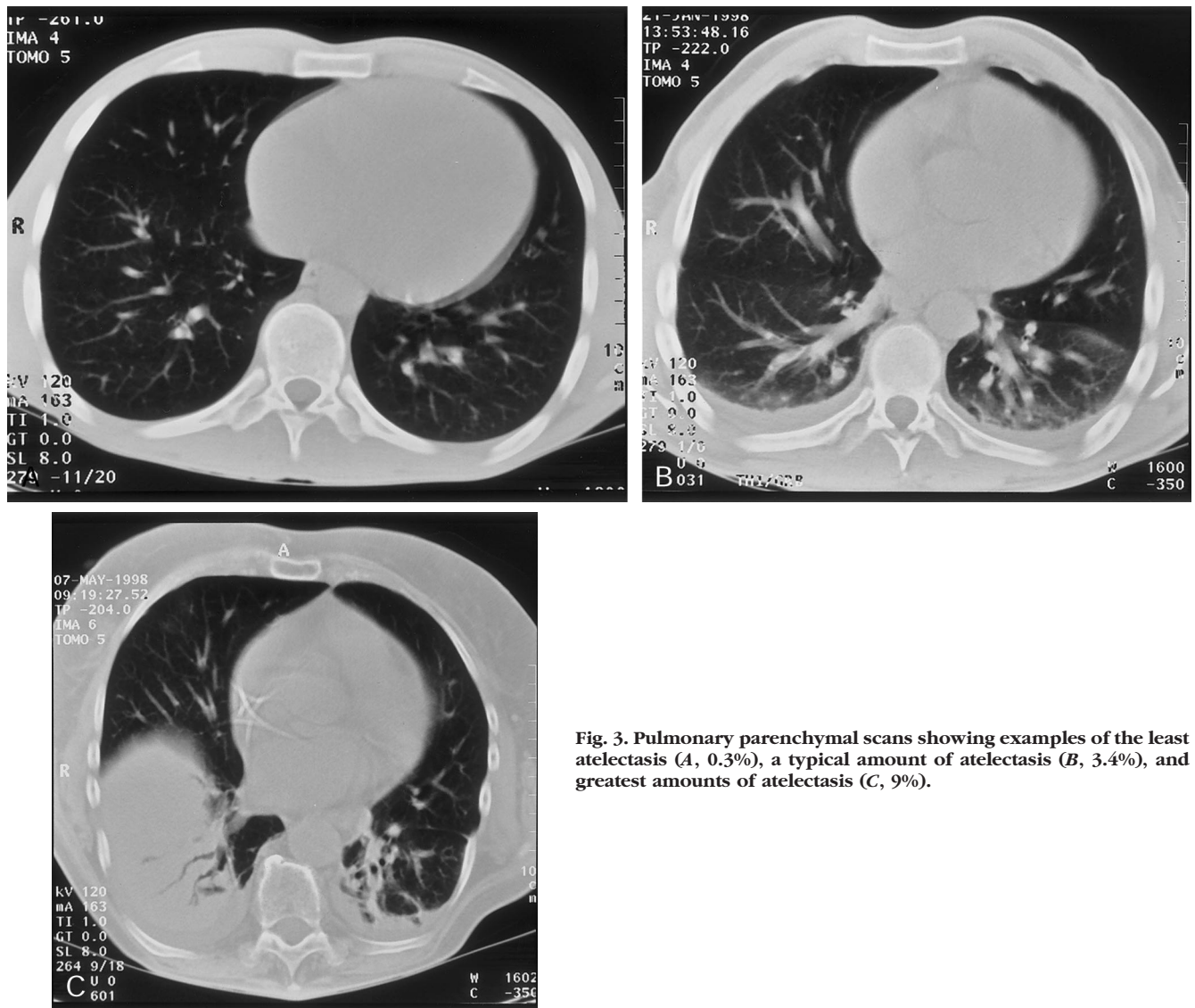


Fig. 3. Pulmonary parenchymal scans showing examples of the least atelectasis (A, 0.3%), a typical amount of atelectasis (B, 3.4%), and greatest amounts of atelectasis (C, 9%).

postoperative day was < 60 mmHg in only three patients (one given 80% oxygen and two given 30% oxygen); their atelectasis rates ranged from 4.4% to 9%. One of these patients required supplemental oxygen to maintain pulse oximeter oxygen saturation $> 92\%$. The same patient developed a fever of 38.1°C on the first postoperative day that subsequently resolved without treatment.

Among the 500 patients who participated in the multicenter infection study, 250 were given 30% oxygen and 250 were given 80% oxygen. Pulse oximetry oxygen saturation measurements on the first postoperative morning were virtually identical in the two study groups:

94 ± 3 mmHg *versus* 94 ± 3 mmHg for the 30%-oxygen and 80%-oxygen groups, respectively. Postoperative chest radiographs in these patients were not specifically scored for atelectasis. However, atelectasis was recorded when it was noted in the radiologic report. The incidence was 31% in patients given 30% oxygen and 36% in those given 80% oxygen ($P =$ not significant).

Discussion

Numerous factors contribute to perioperative atelectasis, including anesthesia-related reduced lung compliance, airway closure, reduced functional residual capacity in the supine position, and pain-induced restriction of

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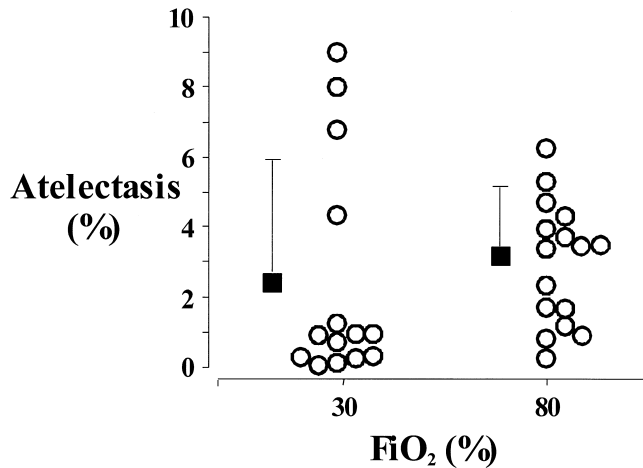


Fig. 4. Amounts of atelectasis detected by computed tomography in patients given 30% and 80% perioperative oxygen.

diaphragmatic movement.^{3,33,34} Surgical factors also contribute to ventilation-perfusion mismatch by causing regional differences in diaphragmatic movement and changes in the elastic properties of the lung.^{35,36} Intestinal distension and restrictive abdominal bandages further impair recovery of normal diaphragm function.³⁷ Intraoperative positive end-expiratory pressure was initially thought to minimize development of atelectasis. However, it was subsequently shown that atelectasis nonetheless develops as soon as treatment is discontinued.³⁸

High inspired oxygen concentrations—even for brief periods of time—have been shown to induce atelectasis.^{7,8} The average amount of atelectasis in our patients was similar to that observed previously.¹¹ Furthermore, the incidence and severity of atelectasis and poorly aerated regions on the first postoperative day were comparable in patients given either 30% or 80% inspired oxygen in the perioperative period. Consistent with this observation, the incidence of atelectasis as diagnosed by chest radiographs were comparable in the two large groups of patients participating in the multicenter Study of Oxygen and Surgical Wound Infection. These results therefore indicate that oxygen-induced atelectasis is a short-term effect that resolves spontaneously—even before patients are mobilized or receive physical therapy.

The major clinical consequence of atelectasis is shunt. The normal (Aa)D_{O₂} during inspiration of room air is approximately 10 mmHg, but it increases to 70 mmHg with 100% oxygen and also increases with age. An (Aa)D_{O₂} of 15 mmHg is therefore generally accepted as normal at age 70 yr. Abnormally high values are espe-

cially associated with ventilation-perfusion imbalance and impaired diffusion across the alveolar-capillary membrane. The (Aa)D_{O₂} is thus a useful way to evaluate shunt resulting from atelectasis-induced alveolar collapse.³⁹

The (Aa)D_{O₂} values we observed on the first postoperative day (approximately 30 mmHg) were slightly elevated, although the magnitude of this increase is of questionable clinical importance. However, there was no difference between the groups. This is consistent with previous studies in which similar amounts of atelectasis (1–4%) were not associated with clinically important impairment of pulmonary function.^{1,2} It is also consistent with our observation that oxygen saturation on the first postoperative day was virtually identical in the two large groups of patients enrolled in the multicenter study. These results are consistent with the atelectasis data and indicate that perioperative administration of 80% oxygen does not worsen pulmonary gas exchange. Comparable forced vital capacity and forced expiratory volume in the first second in the two groups similarly indicate that 80% oxygen does not provoke any impairment in lung volumes lasting until the first postoperative day.

Numerous previous studies identify oxygen-induced atelectasis in the immediate postoperative period, often accompanied by detectable abnormalities in gas exchange.^{2,7–12} However, our purpose was to evaluate pulmonary dysfunction that persisted for a clinically relevant period. We therefore intentionally delayed our formal evaluation of lung function to the first postoperative day. We tested 80% oxygen because this concentration provides many of the benefits of 100% oxygen but with less direct pulmonary toxicity. It therefore remains possible that administration of 100% perioperative oxygen is associated with clinically important atelectasis.

In summary, lung volumes, the incidence and severity of atelectasis, as well as alveolar gas exchange were comparable in patients given 30% and 80% oxygen during and for 2 h after colon resection. We conclude that administration of 80% oxygen in the perioperative period does not worsen lung function. Therefore, patients who may benefit from generous oxygen partial pressures should not be denied supplemental perioperative oxygen for fear of causing atelectasis.

The authors gratefully acknowledge the support and generous assistance of the CT technicians, Marlene Thiem, R.T.A., and Sylvia Kiss,

R.T.A., and the generous contributions of Alois Werba, M.D., Cem F. Arkiliç, M.D., and Folke Seibt, M.D.

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